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The Use of Catch–Effort, Catch–Sampling, and Tagging Data to Estimate a Population of Blue Crabs[1]

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ABSTRACT

Catch–effort, and catch–sampling data along with the results of a tagging study are used to estimate the size of the blue crab, *Callinectes sapidus*, population in the Neuse River, North Carolina, during 1958. At the beginning of July, estimates of the crab population, determined by three methods, were 716,000, 703,000, and 722,000 pounds, respectively. Catch, recruitment, and emigration of mature female crabs from the river affected abundance, whereas natural mortality and predation upon crabs were considered insignificant. Of the 2.1 million pounds of crabs estimated as being available to the fishery during 1958, 1.7 million pounds were caught.

INTRODUCTION

During the past 50 years, and especially in the past two decades, large and sudden declines in abundance of the blue crab, *Callinectes sapidus,* along the Atlantic coast of the United States have adversely affected the crab industry. As a result, the crab industry, through the Atlantic States Marine Fisheries Commission, asked the U. S. Fish and Wildlife Service to undertake a research program to determine causes of fluctuations, and to recommend measures for obtaining optimum continuing yields from the resource. One phase of this program was the estimation of crab abundance so that effects of factors affecting abundance could be assessed.

The U. S. Fish and Wildlife Service began work on blue crabs in 1957, and in 1958 the commercial fishery for blue crab in the Neuse River, North Carolina, was studied. The purpose of the study was to develop methods of estimating abundance that would apply to the population in this river and would aid in understanding the dynamics of crab populations in other areas. This paper presents three methods used to estimate the size of the crab population in the Neuse River from the spring to the fall of 1958.

LIFE HISTORY OF THE BLUE CRAB

Sexual maturity of crabs in Chesapeake Bay is reached in about 1½ years and after approximately 27 molts following hatching (Van Engel, 1958; Costlow and Bookhout, 1959). In the Neuse River the number of molts until sexual maturity is believed to be the same, but the period of time for these molts is shorter.

Young crabs move into the Neuse River from Pamlico Sound (Figure 1). Growth, which occurs at molting, takes place from spring to fall. Before a crab molts, a new skin or shell is formed beneath the hard outer shell. A crab approaching the time of shedding is called a "peeler" crab. After the hard shell is shed, the new, soft, pliable outer covering expands and begins to harden. Within approximately 24 hours the shell has hardened so that a crab cannot be marketed as a "soft" crab.

After their last molt, and while still soft, female crabs mate and then move from the river into the more saline waters of Pamlico

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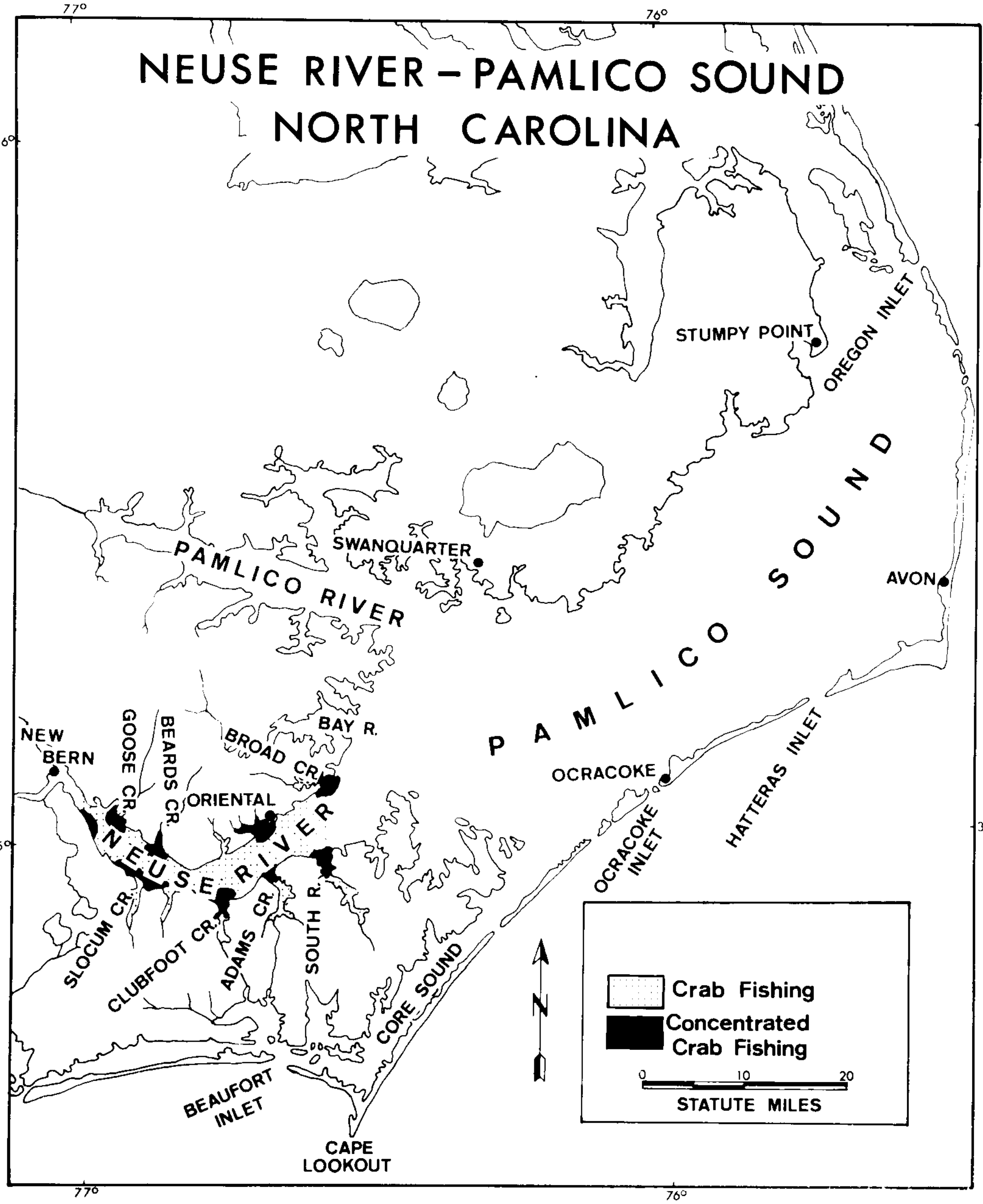

FIGURE 1.—Neuse River–Pamlico Sound, North Carolina.

and Core Sounds. Mating, and the movement of the females, occurs mainly from May to October. The males remain in the river until fall. Spawning females produce large numbers of eggs which become attached to the abdominal appendages. Female crabs with large numbers of eggs attached to their abdomens are called "sponge" crabs. After approximately 2 weeks, the eggs hatch into a planktonic larval form, the zoea. After several zoeal stages, the larvae become megalops, and at the next molt assume the crab appearance.

Adult size is attained in approximately 1 year.

Additional information on the life history, including bibliographies of the literature on the blue crab in North Carolina and in Chesapeake Bay, may be found in Pearson (1951) and Van Engel (1958).

THE RIVER AND THE CRAB FISHERY

The commercial fishery for crabs on the Neuse River begins approximately 8 miles below New Bern, N. C., and extends downriver into Pamlico Sound. For the purpose of this study, the lower boundary of the river fishery is considered to be 40 miles below New Bern, east of Broad Creek on the north and east of South River on the south bank (Figure 1). All catches below this point are considered to be from the Pamlico Sound fishery. The 40-mile section of river below New Bern is a sluggish coastal stream varying from 1 to 6 miles wide, with a flat gradient to Pamlico Sound. There is virtually no tidal influence in this area although it is subject to fluctuations due to wind.

Trotlines and otter trawls are the major crab fishing gears in the Neuse River. The trotline is a baited line laid on the river bottom, and, as the line is raised, feeding crabs are brought to the surface where they are caught in a dip net. Trotlines usually are fished in 3 to 8 feet of water in the mouths of the tributaries or in the river near the tributaries. Wharton (1954) and Van Engel (1962) further described the trotline and the method of fishing this gear. Most otter trawls are 33 feet across the mouth and are pulled along the bottom in water from 5 to 15 feet deep by trawlers 25 feet in length. Trawls used mainly for catching crabs have cod ends with 4 inches stretched mesh, and trawls fished primarily for shrimp have cod ends with 1¾ inches stretched mesh. In this paper trawls with 4 inches stretched mesh in cod ends are classified as crab trawls and those with the smaller mesh are classified as shrimp trawls. Both crab and shrimp trawls are fished in and near the mouths of Broad and Adams Creeks, South River, and in the vicinity of Oriental (Figure 1).

MATERIALS AND METHODS

The sources of information used to derive estimates of the crab population in the Neuse River were catch–effort data, data obtained from sampling the catch, and the results of a tagging study.

Catch–effort data

Each fisherman's catch by gear, day, and locality was obtained from crab dealers. Catches by week for trotlines and crab and shrimp trawls are given in Table 1. Crab pots and oyster dredges, which caught 3,527 pounds (mostly in March, April, October, and November), are not included in Table 1. Included in the crab and shrimp trawl catches are 11,141 pounds of soft or peeler crabs. A few female soft crabs are included in the trotline catches. These soft female crabs were mating and were being carried by male crabs which fed on the trotline baits. Therefore, when the mating males were caught, so were the soft female crabs. Generally, trotline fishermen do not separate the few soft crabs when marketing their catch.

Following is the procedure used to standardize the effort for the major types of crabbing gear. Units of trotline, crab trawl, and shrimp trawl effort are recorded by week (Table 1), and each unit represents one trotline or trawl, respectively, fished during 1 day. The average catches per day were 245.8, 350.0, and 261.9 pounds for trotlines, crab trawls, and shrimp trawls. Letting the average catch per day of a trotline represent the catch of a standard fishing unit, the fishing powers (Ricker, 1958) of crab and shrimp trawls relative to the catch of a standard unit were 1.42 and 1.06, respectively (Table 1). Standard fishing units, representative of the effort of crab and shrimp trawls, were calculated by dividing crab trawl and shrimp trawl effort by the respective fishing powers of these gears. The total standard fishing units of the three gears during each week was divided into the total weekly catch to obtain an estimate of the catch per standard unit of effort during each week (Table 1).

Tag-and-recovery data

During 1958, crabs of 5 or more inches in carapace width were tagged and released in the crab fishing areas of the Neuse River (Table 2). All tagged females were adults

TABLE 1.—*Catch statistics of blue crab in the Neuse River by weeks beginning 7 April 1958 and ending 9 November 1958*

Week	Trotline		Crab trawl			Shrimp trawl			Total		Catch per standard fishing unit
	Catch	Effort	Catch	Effort		Catch	Effort		Catch	Effort	
	Pounds	Trotline days or standard fishing units	Pounds	Crab trawl days	Standard fishing units	Pounds	Shrimp trawl days	Standard fishing units	Pounds	Standard fishing units	Pounds
1			261	2	3				261	3	87.0
2	154	2	6,624	14	20				6,778	22	308.1
3	271	4	26,698	65	92				26,969	96	280.9
4	737	7	15,780	91	129				16,517	136	121.4
5	1,276	9	10,356	68	96				11,632	105	110.8
6	9,252	61	34,090	121	172				43,342	233	186.0
7	33,452	125	39,909	123	175				73,361	300	244.5
8	33,054	169	34,493	91	129				67,547	298	226.7
9	39,674	222	38,749	114	162	278	2	2	78,701	386	203.9
10	51,995	291	36,195	109	155	2,753	16	17	90,943	463	196.4
11	59,474	241	65,236	133	189	7,517	21	22	132,227	452	292.5
12	30,779	173	30,732	86	122	11,568	50	53	73,079	348	210.0
13	38,000	197	12,059	50	71	10,237	40	42	60,296	310	194.5
14	60,726	196	15,163	36	51	21,486	80	85	97,375	332	293.3
15	61,666	198	23,105	35	50	33,636	68	72	118,407	320	370.0
16	57,999	170	18,729	35	50	30,911	82	87	107,639	307	350.6
17	61,463	165	16,310	33	47	34,346	83	88	112,119	300	373.7
18	50,776	192	6,493	21	30	26,565	88	93	83,834	315	266.1
19	56,533	195	7,570	21	30	36,810	135	143	100,913	368	274.2
20	54,074	179	3,450	14	20	33,554	115	122	91,078	321	283.7
21	22,770	75	2,459	9	13	33,783	132	140	59,012	228	258.8
22	36,026	155	1,821	4	6	25,106	97	103	62,953	264	238.4
23	34,833	152	3,118	5	7	31,834	117	124	69,785	283	246.6
24	28,117	123	1,723	4	6	17,288	98	104	47,128	233	202.3
25	20,157	92	867	4	6	17,434	121	128	38,458	226	170.2
26	7,093	42				462	13	14	7,555	56	134.9
27	5,421	37	12	1	1	1,649	31	33	7,082	71	99.7
28	8,115	38				1,953	38	40	10,068	78	129.1
29			225	1	1	516	8	8	741	9	82.3
30	1,982	12	631	3	4	1,959	20	21	4,572	37	123.6
31	212	1	816	3	4	700	5	5	1,728	10	172.8
Total	866,081	3,523	453,674	1,296	1,841	382,345	1,460	1,546	1,702,100	6,910	
Catch per unit of effort (pounds)		245.8		350.0			261.9				
Fishing power in relation to trotline		1.00		1.42			1.06				

and would not molt. There was no method of determining whether tagged males were fully grown or whether they would continue to molt. Tagging began the last of April and continued at semimonthly intervals until the end of September. The number of tagged crabs released in each area of the river was based upon the expected abundance in the areas, so that the ratios of tagged to untagged crabs in each area would be approximately equal. Suggestions regarding expected abundance in the areas were obtained from fishermen and from examination of catch records for previous years.

Crabs for tagging were obtained from commercial fishermen. All crabs of the correct width in the catch from a drag or from one or more trotline runs were tagged. At times large quantities of crabs were caught by trawlers and dumped on deck. Since it was not practical to tag all the available crabs in these particular drags and in order to avoid sex or size bias, only crabs occupying a portion of the deck and of the proper size were tagged. Sex and carapace width were recorded before tagging the crabs. A carapace tag (Rounsefell and Everhart, 1953) was attached to each crab with stainless-steel wire, and the crabs were released in the area of capture. The numbered tags carried a reward (25 cents) notice and the name and address of the tagging institution.

A list of the commercial crab fishermen on the river was obtained from the crab dealers. Tag return envelopes were enclosed with letters sent to these fishermen informing them of the tagging study. Newspaper articles and reward notices displayed by crab dealers and at crab picking plants gave added publicity to the tagging program. In addition to tag

TABLE 2.—*Number of tagged crabs released at various locations on the Neuse River and Pamlico Sound, and the tag returns from these releases*

Location released	Released		Returned					
	Males	Females	Males		Females		Total	
	Number	Number	Number	Percentage	Number	Percentage	Number	Percentage
Neuse River								
Goose Creek	741	68	242	33	17	25	259	32
Slocum Creek	132	16	54	41	1	6	55	37
Beards Creek	711	108	316	44	21	19	337	41
Oriental	1,116	302	307	28	51	17	358	25
Adams Creek	182	108	76	42	33	30	109	38
South River	67	38	20	30	4	10	24	23
Total	2,949	640	1,015	34	127	20	1,142	32
Pamlico Sound								
Swanquarter	405	124	72	18	17	14	87	17
Stumpy Point	484	322	98	20	50	16	148	18
Avon	403	437	114	28	100	23	214	25
Ocracoke	27	368	7	26	24	6	31	8
Harbor Island	31	63	6	19	11	17	17	18
Total	1,350	1,314	297	22	202	15	499	19

returns by mail, monthly visits were made to crab dealers and picking plants to obtain recovered tags. Fishermen were contacted frequently for tag returns, and a canvass of each fisherman at the end of the season also accounted for numerous tag returns.

Crabs 5 or more inches in carapace width were also tagged in Pamlico Sound (Table 2). The purpose of this phase of the study was to determine if commercial-size crabs moved from Pamlico Sound into the Neuse River. Approximately 200 crabs, obtained from commercial fishermen, were tagged at bimonthly intervals, beginning in April and continuing into October, in each of five areas of Pamlico Sound. The smaller numbers of crabs tagged at Swanquarter, Ocracoke, and Harbor Island resulted from the intermittent fishery in these areas. Bimonthly contact with the crab fishermen, as well as newspaper articles and reward posters in crab plants situated around the sound, facilitated the return of tags.

Catch sampling

Between April and September 1958, 30 samples of crabs caught by commercial fishermen on trotlines and in trawls were examined to obtain estimates of the sex ratio in the entire catch and the ratio of precommercial- to commercial-size crabs. These samples were taken monthly in five areas of the river, provided a fishery was in operation. Samples were obtained before the fishermen released any of the smaller crabs.

Sampling was continued during the 1959 crabbing season, and, in addition to sex and size, individual live weights also were obtained. Two types of samples were obtained from the fishermen. One type was obtained before the fisherman culled or released the small crabs, and the other after culling.

FACTORS AFFECTING ABUNDANCE

Two main factors, other than catch, affected the size of the commercial crab population in the Neuse River. These were: 1) movement of commercial-size female crabs out of the river, and 2) recruitment. The importance of natural mortality and other factors that might have affected population size will be discussed in a later section.

Movement

Tag returns indicated that during the crabbing season in the river commercial-size crabs of both sexes did not move from Pamlico Sound to the river and that commercial-size male crabs did not move from the river to the sound. However, the returns did indicate movement of commercial-size female crabs from the river to the sound. Movement of females downriver into the sound was also suggested by the samples from the crab catch in the river and from observations of catches made in the river and in Pamlico Sound.

Of the 2,664 crabs tagged in five areas of Pamlico Sound in 1958, 499 or 19% were recovered (Table 2). Twenty-nine of these recoveries, 18 males and 11 females, were made more than 5 miles from the vicinity of release. All of these 29 recoveries were recaptured in the sound, generally to the south or southeast of the area of tagging. No tagged crabs released in Pamlico Sound were recaptured in the Neuse River.

Of the 2,949 tagged males released during 1958 in the river, 1,015 or 34% were recovered (Table 2). Commercial crab fishermen operating in the river recaptured 899 males in 1958, 19 in 1959, and 1 each in 1960 and 1961. Six males were recaptured outside the river in 1958. Only one of these recoveries, made near the mouth of the river in July, indicated that males perhaps moved from the river during the crab-fishing season. The remaining five recoveries were made in late fall and winter near the mouth of the river, in Pamlico Sound. Also during 1958, 32 crabs were recovered in the river by sport fishermen and seven by commercial fishermen fishing for species other than crabs. For 50 returns, data were not available on location, or date of capture, or both.

Of the 640 tagged females released in the river, 127 or 20% were recovered (Table 2). Ninety-nine were recovered in the river in 1958 by crab fishermen, but none were recovered there in 1959, 1960, or 1961. Seven females were recaptured in 1958 and six in 1959 in Pamlico and Core Sounds. One female was recovered in the ocean at Cape Lookout in 1961 (Figure 1). Sport fishermen caught two females in the river during 1958, and one was captured by an oyster dredge fisherman in the fall. For 11 returns, data were not available on location or date of capture, or both.

In addition to the seven tag returns from mature females released in the river and recaptured in the sounds in 1958, the following circumstantial evidence also suggests movement of mature female crabs downriver:

1) Marketing of sponge crabs was illegal in 1958, and crab fishing was usually terminated in areas where these crabs predominated. During late spring and summer, the presence of large numbers of sponge crabs in southeast Pamlico Sound caused a halt in the crab fishery in this area. Therefore, although only a few of the tagged mature females released in the river were recovered in Pamlico Sound, the lack of a substantial fishery in the sound during summer, suggests that these recoveries might represent a larger percentage of females that emigrated from the river.

2) Recently matured females were present in the low salinity water (of the river) and sponge crabs in the higher salinity waters (of the sounds). These were the same conditions found in other areas where downriver migration of mature females occurs (Darnell, 1959; Porter, 1956; Truitt, 1939).

3) Both females and males were recovered from the river for 2 weeks after release of tagged crabs of both sexes in the river, but subsequently only males were taken in the river.

Although sport and commercial fishermen not fishing for crabs accounted for 42 recoveries, the catch of hard crabs retained by these fishermen was small and was not included with the commercial fishery catch–effort data.

Recruitment

Estimates of daily recruitment were calculated from the percentages of precommercial crabs in the 30 samples of unculled catches obtained in 1958. From samples of unculled as well as culled catches in 1959, the minimum size of crabs sold by the fishermen was estimated to be approximately 4.5 inches carapace width. This figure was applied to the 1958 samples, and the crabs between 3.4 and 4.5 inches were designated precommercial-size crabs. The average time for precommercial-size crabs to shed and become commercial-size crabs was considered 17.5 days. The procedure for estimating recruitment from ratios of precommercial- to commercial-size crabs was as follows:

1) During May and June of 1961, studies, reported by Davis (unpublished), were conducted near the mouth of Adams Creek (Figure 1) to determine whether 3.4 inches

and 17.5 days were, respectively, reasonable estimates of the lower limit of precommercial-size crabs and the average molting time. The crabs used in the experiments were caught by commercial fishermen in Adams Creek and South River. No selection was made for crabs in any particular stage of the intermolt cycle. During May and June a total of 251 crabs was placed in compartmented floats at Adams Creek. Sixty-three crabs died without molting, 124 molted (52 males and 72 females), and 64 were alive and unmolted at the end of the experiments on 30 June. Before molting, the 52 male crabs averaged 3.4 inches in width (range, 2.4 to 4.5 inches), and after molting averaged 4.4 inches (range, 3.2 to 5.7 inches). The 72 females averaged 3.6 inches (range, 2.4 to 4.6 inches) before molting and 4.9 inches (range, 3.2 to 6.4 inches) after molting. These results and those of Gray and Newcombe (1939), where Chesapeake Bay crabs averaging 3.4 inches subsequently averaged 4.5 inches after molting, suggest that 3.4 inches is a good estimate of the actual lower limit of precommercial-size crabs in the Neuse River which will be of commercial size (4.5 inches or wider) after molting.

2) Of the 251 crabs used in the experiments at Adams Creek, 170 were put in the floats in May and 81 on 14 June. Of the 170 crabs placed in floats in May, 92 molted, 46 died, and 32 were alive and had not molted by 30 June. Both males and females that molted averaged 8.9 days to molt. The time-to-shed distribution for the crabs that molted (73% of the 92 crabs molted within 7 days) suggests that when the crabs were first placed in the floats there were unequal numbers in various stages of the intermolt cycle. However, if continuous captivity depressed the molting process of crabs that would molt later in the experiment more so than those that would molt shortly after beginning the experiment, and if the mortality rate increased with length of captivity, then these factors could also cause the time-to-shed distribution for the crabs that molted to be positively skewed. Therefore, because of possible effects of captivity on the time-to-shed distribution the arithmetic mean of the times-to-shed (8.9 days), rather than another measure such as the median number of days, was considered the best estimate representative of the average time-to-shed for precommercial crabs in the Neuse River.

It was assumed (1) that the crabs in the experiments at Adams Creek were representative of the precommercial crabs in the Neuse River and its tributaries, and (2) that 8.9 days was the average time for precommercial-size crabs to shed. Approximately twice the value of 8.9, 17.5 days, was considered the total time to shed for precommercial crabs. Therefore, assuming that in a sample of crabs 3.4 to 4.5 inches carapace width there are equal numbers of crabs in all stages of the molt cycle, then 1/17.5 of these crabs could be expected to shed each day.

The results of the experiment at Adams Creek have been used to attempt a justification for an average molting rate per day of 0.0571 (1/17.5) for precommercial crabs. This rate, based on experiments where 46% of the crabs died or did not molt, may be incorrect. However, a comparison of recruitment rates calculated from a molting rate of 0.0571 per day agreed with the recruitment rates calculated from the ratio of soft to hard crabs in the catch (see Discussion).

3) From the crab weight–width relation estimated from the samples of crabs obtained in 1959, the weight was estimated of the 1958 samples of precommercial-size crabs after molting (Table 3). This estimated weight of male and female recruits for each sample was reduced by an estimate of mortality during molting (7%), and by a factor of unavailability to the fishery for commercial-size females (0.44). The estimate of 7% mortality during molting was obtained from studies by Robertson (unpublished). Although he worked with crabs smaller than precommercial sizes, he found an almost constant 7% mortality between molts. The factor of 0.44 for relative unavailability of females to the fishery was

TABLE 3.—*Estimated daily recruitment rates calculated from 30 catch samples, Neuse River, 1958*

Area	Date	Number of precommercial-size crabs		Estimated weight of precommercial crabs after molting[1] (grams)			Estimated weight of commercial-size crabs (grams)	Ratio[2]	Daily recruitment rate (percentage)
		Male	Female	Male	Female	Total			
Goose Creek	23 May	54	26	6,932	1,432	8,364	11,944	0.700	4.0
" "	9 July	37	6	4,943	310	5,253	12,333	0.430	2.4
" "	17 July	36	14	4,350	716	5,066	11,543	0.439	2.5
Beards Creek	19 June	49	24	6,213	1,309	7,522	5,966	1.261	7.2
" "	11 July	25	9	3,116	216	3,332	12,266	0.272	1.6
" "	14 Aug.	23	15	2,837	808	3,645	12,784	0.285	1.6
" "	3 Sept.	27	23	3,450	1,187	4,637	10,404	0.446	2.5
" "	24 Apr.	20	16	2,295	853	3,148	11,491	0.274	1.6
" "	13 May	13	12	1,848	681	2,529	11,258	0.225	1.3
" "	22 May	20	3	2,569	174	2,743	17,976	0.152	0.9
Oriental	5 June	42	34	5,107	1,804	6,911	7,409	0.933	5.3
"	1 July	31	33	4,047	1,711	5,758	11,528	0.499	2.8
"	30 July	18	10	2,532	541	3,073	16,799	0.183	1.0
"	26 Aug.	17	17	2,134	900	3,034	16,114	0.188	1.1
"	24 Sept.	9	8	1,150	443	1,593	15,339	0.104	0.6
"	9 May	22	21	2,914	1,109	4,023	7,895	0.510	2.9
"	2 June	17	25	2,159	1,281	3,440	11,618	0.296	1.9
"	30 June	24	13	3,080	701	3,781	11,549	0.327	1.9
"	30 July	23	33	2,783	1,798	4,581	12,045	0.380	2.2
"	29 Aug.	14	18	1,713	965	2,678	12,470	0.215	1.2
Adams Creek	29 Apr.	20	20	2,496	1,012	3,508	9,384	0.374	2.1
" "	23 June	31	38	3,705	1,921	5,626	8,134	0.692	4.0
" "	25 July	6	4	839	433	1,272	10,738	0.118	0.7
" "	20 Aug.	10	14	1,258	729	1,987	11,408	0.174	1.0
" "	18 Sept.	18	25	2,136	1,268	3,404	13,488	0.252	1.4
South River	23 July	25	24	3,208	1,261	4,469	12,855	0.348	2.0
" "	27 May	12	13	1,502	628	2,130	7,993	0.266	1.5
" "	26 June	12	17	1,549	832	2,381	13,660	0.174	1.0
" "	21 Aug.	18	27	2,085	1,392	3,477	11,618	0.299	1.7
" "	18 Sept.	10	27	1,140	1,434	2,574	10,684	0.241	1.4

[1] Reduced by 7% for estimated mortality while molting, and the females reduced by an additional 44% (see text).
[2] Consists of the estimated weight of precommercial crabs after molting divided by the weight of commercial-size crabs.

obtained from the tagging study in the river. Of the females released in the river, 18% were recaptured in the river in 1958, compared with a 32% return for tagged males. The difference between the two percentages (14) divided by the percentage return for tagged males (32) was the estimate, 0.44, of the proportion of precommercial-size female crabs that after molting escaped the fishery and moved from the river. Neither varying ratios of the number of male to female crabs tagged during the fishing season nor from the different fishing areas, could have caused the unequal percentage returns from the sexes.

Briefly, the method of calculating recruitment rates from a catch sample was to estimate the weights of precommercial males and females after molting, reduce them by 7%, and then further reduce the weight of the females by 44%. These weights were then divided by the estimated weight of commercial-size crabs in the samples and by 17.5 to obtain estimates of daily recruitment rates (Table 3). The calculated rates are estimates of the percentage increase in the crab population of commercial size in the various fishing areas on the days of sampling. In Table 4 are unweighted average estimates of the daily recruitment rates shown in Table 3 during semimonthly periods from 1 May to 30 September.

POINT ESTIMATES OF POPULATION SIZE

Three methods, designated as the Leslie, Alternate, and Parker methods, were used to obtain point estimates of the size of the commercial crab population in the Neuse River during 1958.

Leslie method

This method (Leslie and Davis, 1939; Ricker, 1958) of estimating population size was applied to the 1958 Neuse River crab catch and effort data. It "involves plotting the catch per unit effort against cumulative catch over a period of time" (Ricker, 1958). If the plot gives an acceptably straight line, initial population size and catchability can be estimated.

TABLE 4.—*Estimates of daily recruitment rates during semimonthly periods, Neuse River, 1958*

Period	Daily recruitment rate (percentage)
1–15 May	2.1
16–31 May	2.1
1–15 June	3.5
16–30 June	3.5
1–15 July	2.3
16–31 July	1.6
1–15 August	1.6
16–31 August	1.2
1–15 September	2.5
16–30 September	1.1

When applying this method, it is necessary that (1) changes in availability and vulnerability be negligible as the fishing season progresses, (2) movements of the population out of the fishing area and of other populations into the area also be negligible, and (3) recruitment either balance natural mortality and predation, or that these factors be insignificant during the fishing season. For the present, changes in availability, vulnerability, and therefore catchability will be considered insignificant, and natural mortality and predation will be considered negligible. Because of the possible bias these factors might introduce into the various methods of population estimation that will be presented, and because some assumptions were not completely fulfilled, they will be more fully discussed in a later section of this paper.

To satisfy the condition for no movement, only catch and effort data for males were used because the tagging and catch sampling studies indicated commercial-size females moved out of the river while the fishery was operating. To correct for the weight of male recruits in the weekly catches of male crabs after a particular day ($t = 0$), the proportion of recruits was first estimated and then subtracted from the weekly catches. The remainder of the catch each week was considered to be from the male population at $t = 0$, and was supposedly free of recruits. Estimates of the number of standard fishing units for each week were calculated, and these data, together with the catch data, were used in the Leslie method to estimate the population of male crabs.

Immediately following are the methods used to estimate the weight of male crabs in

TABLE 5.—*Percentage by weight of commercial-size crabs in catch samples, Neuse River, 1958*

Area	Gear	Apr.	May	June	July	Aug.	Sept.
Beards Creek	Trotline			74	90	80	77
	Crab trawl	88	86	—[1]	—[1]	—[1]	—[1]
Goose Creek	Trotline		84		85		
		—[1]	74		83		
Adams Creek	Shrimp trawl	—[1]	—[1]		39	65	65
	Crab trawl	73		73		—[1]	—[1]
Oriental	Trotline			71	77	77	96
					82		
	Crab trawl		85	78			
				89			
	Shrimp trawl	—[1]	—[1]		74	76	
South River	Trotline	—[1]			83		
	Shrimp trawl	—[1]	—[1]			79	58
	Crab trawl		75	66		—[1]	—[1]
Average		80	81	75	77	75	74

[1] No crabs caught by the specified gear during the month.

the weekly catches, the procedure to correct these catches for recruits, and the estimation of population size.

The estimated percentage by weight of commercial-size males to the total weight of males and females was calculated for each of the 30 catch samples (Table 5). The number of commercial-size crabs in a sample ranged from 52 to 119. For each of the three major types of gear fished, the estimated monthly catch of males in the various areas of the river was obtained by multiplying the total catch in the area by the estimate of the percentage of males estimated from the 30 catch samples. However, only the calculations for estimating the catch of male crabs by crab trawls is shown (Table 6). Where a sample of crabs was not taken in an area during a month or from the particular type of gear, the average proportion of males from all samples taken during the month was used as the estimate of the proportion of male crabs in the monthly catch.

The ratios of males in the total catch by gear for each month were then applied to the total catch by each type gear for each week (Table 7). From this the total male catch by week was obtained (last column of Table 7). Although the catches of male crabs by gear and week (Table 7) implies completeness of the data, they were based on only the 30 catch samples obtained from the commercial fishery.

Estimates of daily recruitment rate for

TABLE 6.—*Calculation of pounds of commercial-size male crabs caught by crab trawls, Neuse River, 1958*

Area		Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Beards Creek	Total catch	8,174	13,329						
	Ratio males	0.88	0.85						
	Catch males	7,193	11,330						
Adams Creek and South River	Total catch	310	9,341	9,562	8,572				
	Ratio males	0.80[1]	0.81[2]	0.75[3]	0.77[4]				
	Catch males	248	7,566	7,172	6,600				
Oriental	Total catch	37,402	99,655	166,195	71,823	20,098	7,529	868	816
	Ratio males	0.80[1]	0.85	0.84	0.77[4]	0.75[5]	0.74[6]	0.74[6]	0.74[6]
	Catch males	29,922	84,707	139,604	55,304	15,074	5,571	642	604
Total catch		45,886	122,325	175,757	80,395	20,098	7,529	868	816
Catch of males		37,363	103,603	146,776	61,904	15,074	5,571	642	604
Proportion of males		0.81	0.85	0.84	0.77	0.75	0.74	0.74	0.74

[1] Average of 2 samples taken in month of April.
[2] Average of 5 samples taken in month of May.
[3] Average of 6 samples taken in month of June.
[4] Average of 8 samples taken in month of July.
[5] Average of 5 samples taken in month of August.
[6] Average of 4 samples taken in month of September.

males to the commercial-size male population were calculated from the 30 catch samples in the same manner as the recruitment rate estimates presented in Table 3 for both males and females. The estimates of daily recruitment rate for males were applied to the catches of male crab by area, gear, and month. Only the calculations of the estimated catch of male recruits by trotlines are shown (Table 8). When estimates of daily recruitment rate were not available for males in a particular area or by a particular gear, the average rate from all samples during the month was used. The recruitment rate for a month was asssumed to be the number of days in a month multiplied by the daily rate. The monthly rates were divided in half before applying them to the monthly male catches. This was necessary to give a better estimate of the pounds of recruits in any monthly catch as the proportion of recruits in the daily catch at the beginning of the month was negligible, but the last day of the month was at least equal to the cumulative daily recruitment rate during the month minus recruit mortality previous to the last day of the month. The cumulative daily recruitment rate for a month divided by two was considered the best simple ratio to apply to the monthly catch. When the catch of male recruits was estimated to be greater than the catch in a month for an area, the recruits were considered to equal the monthly catch. An example of this is the estimate of the recruits in the trotline catch at Beards Creek during June (Table 8).

Assuming a daily recruitment rate of 0.017 at Beards Creek during April (Table 8), the monthly recruitment rate should be 0.017×30, which equals 0.510. However, the trotline fishery began on 18 April in this area, and therefore the daily rate (0.017) was multiplied by 13, the number of days from 18 to 30 April, inclusive, to obtain the estimate of the monthly recruitment rate (0.221) during the period in April when trotlines operated at Beards Creek. This figure was halved to give the estimate (0.110) of the ratio of recruits in the catch. The product of the catch (862 pounds) multiplied by 0.110, gives an estimate of the crabs recruited in April that were caught during the same month (95 pounds).

In the last three lines of Table 8 are estimates for each month of the total catch of male crabs by trotlines, the male crabs recruited during the month and caught the same month, and the proportion of the trotline catch of males recruited and caught during the month. Proportions of this kind for the catches by shrimp and crab trawls were then calculated (not shown).

To obtain the proportion of recruits in the weekly catches (columns 3, 6, 9; Table 9), the proportions in the monthly catches (last line of Table 8 for the trotline catches) were divided by 30 or 31 and the quotient multiplied by 7. In the last three columns of Table 9 are estimates of the weekly catch by all gears of male crabs, the male crabs recruited during each week and caught the same week,

TABLE 7.—*Estimated pounds of commercial-size male crabs caught each week in 1958*

Beginning of week	Trotline			Crab trawl			Shrimp trawl			Total catch of males
	Catch	Ratio of males	Catch of males	Catch	Ratio of males	Catch of males	Catch	Ratio of males	Catch of males	
7 April				261	0.81	211				211
14 April	154	0.80	123	6,624	0.81	5,365				5,488
21 April	271	0.80	217	26,698	0.81	21,625				21,842
28 April	737	0.80	590	15,780	0.83	13,097				13,687
5 May	1,276	0.80	1,021	10,356	0.85	8,803				9,824
12 May	9,252	0.80	7,402	34,090	0.85	28,976				36,378
19 May	33,452	0.80	26,762	39,909	0.85	33,923				60,685
26 May	33,054	0.79	26,113	34,493	0.85	29,319				55,432
2 June	39,674	0.74	29,359	38,749	0.84	32,549	278	0.75	208	62,116
9 June	51,995	0.74	38,476	36,195	0.84	30,404	2,753	0.75	2,065	70,945
16 June	59,474	0.74	44,011	65,236	0.84	54,798	7,517	0.75	5,638	104,447
23 June	30,779	0.74	22,776	30,732	0.84	25,815	11,568	0.75	8,676	57,267
30 June	38,000	0.82	31,160	12,059	0.78	9,406	10,237	0.66	6,756	47,322
7 July	60,726	0.83	50,402	15,163	0.77	11,676	21,486	0.64	13,751	75,829
14 July	61,666	0.83	51,183	23,105	0.77	17,791	33,636	0.64	21,527	90,501
21 July	57,999	0.83	48,139	18,729	0.77	14,421	30,911	0.64	19,783	82,343
28 July	61,463	0.80	49,170	16,310	0.76	12,396	34,346	0.68	23,355	84,921
4 Aug.	50,776	0.77	39,098	6,493	0.75	4,870	26,565	0.74	19,658	63,626
11 Aug.	56,533	0.77	43,530	7,570	0.75	5,678	36,810	0.74	27,239	76,447
18 Aug.	54,074	0.77	41,637	3,450	0.75	2,588	33,554	0.74	24,830	69,055
25 Aug.	22,770	0.77	17,533	2,459	0.75	1,844	33,783	0.74	24,999	44,376
1 Sept.	36,026	0.80	28,821	1,821	0.74	1,348	25,106	0.68	17,072	47,241
8 Sept.	34,833	0.80	27,866	3,118	0.74	2,307	31,834	0.68	21,647	51,820
15 Sept.	28,117	0.80	22,494	1,723	0.74	1,275	17,288	0.68	11,756	35,525
22 Sept.	20,157	0.80	16,126	867	0.74	642	17,434	0.68	11,855	28,623
29 Sept.	7,093	0.76	5,391				462	0.72	333	5,724
6 Oct.	5,421	0.74	4,012	12	0.74	9	1,649	0.74	1,220	5,241
13 Oct.	8,115	0.74	6,005				1,953	0.74	1,445	7,450
20 Oct.				225	0.74	166	516	0.74	382	548
27 Oct.	1,982	0.74	1,467	631	0.74	467	1,959	0.74	1,450	3,384
3 Nov.	212	0.74	157	816	0.74	604	700	0.74	518	1,279
Total	866,081		681,041	453,674		372,373	382,345		266,163	1,319,577

and the ratio of these recruits to the total weekly catch of males.

After subtracting the catch of recruits to the male population in a given week from the catch of this week, the remainder represents the catch during the week from the population present at the beginning of the week. This residual can be partitioned into the catch from the population present a week earlier, and the catch of recruits that entered the population the week previous. Beginning with the catch of males during the week of 12–18 May, and applying the estimated weekly ratios of male recruits (last column of Table 9), the catch of recruits during each week was obtained (Table 10). The catch of males during the week of 19–25 May is used as an example to illustrate the partitioning of weekly catches in Table 10. An estimated 60,685 pounds of male crabs were caught, and the best simple estimate of the proportion of the catch of crabs recruited and caught during the week was 0.076 of the catch (week 7, Table 9), or 4,612 pounds. The remaining 56,073 pounds of the catch of male crabs during the week 19–25 May was estimated to be from the population present just prior to 19 May. From this 56,073 pounds can be extracted an estimate of the catch of the crabs recruited to the population in the week 12–18 May. Recruits during the week ending 18 May were estimated to have equaled 0.156 of the population at the beginning of the week. The figure 0.156 is double the estimated proportion of crabs caught during week 6 (12–18 May, last column of Table 9) that were recruited during the sixth week, 12–18 May. It was assumed that the recruitment rate for a week was double the proportion of the catch caught during the week that was recruited the same week. Therefore, the following week, 19–25 May, the catch of crabs recruited during the week previous was estimated to be 15.6% of 56,073 pounds, or 8,747 pounds. The residual of 47,326 pounds is the estimate of crabs, caught during the week of 19–25 May, that were from the commercial male population present just prior to 12 May (Table 10). In Table 10 are listed the estimated male catches each week (column 3), the estimated proportion of recruits each week in the catch of residuals (column 5), the pounds of crabs caught each week that were recruited to the population in a given week (column 6), and

TABLE 8.—*Calculation of the catch of male recruits by trotlines, 1958*

Area		Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Beards Creek	Total male catch	862	21,926	49,701	62,792	30,506	16,043	1,116	
	Daily rec. rate[1]	0.017[6]	0.021[7]	0.081	0.016	0.016	0.025	0.013[11]	
	Mon. rec. rate[2]	0.221	0.651	2.430	0.496	0.496	0.750	0.130	
	% rec. catch[3]	11.0	32.6	121.5	24.8	24.8	37.5	6.5	
	Rec. lbs.[4]	95	7,148	49,701	15,572	7,565	6,016	72	
Goose Creek	Total male catch		12,094	26,547	46,226	32,068	27,131	7,074	
	Daily rec. rate[1]		0.045	0.035[8]	0.026	0.012[10]	0.013[11]	0.013[11]	
	Mon. rec. rate[2]		0.810	1.050	0.806	0.372	0.390	0.390	
	% rec. catch[3]		40.5	52.5	40.3	18.6	19.5	19.5	
	Rec. lbs.[4]		4,898	13,937	18,629	5,965	5,290	1,379	
Slocum Creek	Total male catch		7,882	18,003	16,657	4,005			
	Daily rec. rate[1]		0.021[7]	0.035[8]	0.018[9]	0.012[10]			
	Mon. rec. rate[2]		0.567	1.050	0.558	0.216			
	% rec. catch[3]		28.4	52.5	27.9	10.8			
	Rec. lbs.[4]		2,238	9,452	4,647	432			
Oriental	Total male catch	67	12,191	18,016	67,164	45,187	30,129	1,005	
	Daily rec. rate[1]	0.017[6]	0.021[7]	0.055	0.018	0.010	0.004	0.013[11]	
	Mon. rec. rate[2]	0.119	0.651	1.650	0.558	0.310	0.120	0.130	
	% rec. catch[3]	6.0	32.6	82.5	27.9	15.5	6.0	6.5	
	Rec. lbs.[4]	4	3,974	14,863	18,739	7,004	1,808	6.5	
South River	Total male catch		4,016	18,465	24,662	22,474	13,512	3,373	
	Daily rec. rate[1]		0.021[7]	0.035[8]	0.017	0.012[10]	0.013[11]	0.013[11]	
	Mon. rec. rate[2]		0.231	1.050	0.527	0.372	0.390	0.221	
	% rec. catch[3]		11.6	52.5	26.4	18.6	19.5	11.0	
	Rec. lbs.[4]		466	9,694	6,511	4,180	2,635	371	
Lower Broad Creek	Total male catch		3,144	8,850	8,929	7,888	11,691	1,345	157
	Daily rec. rate[1]		0.021[7]	0.035[8]	0.018[9]	0.012[10]	0.013[11]	0.013[11]	0.013[11]
	Mon. rec. rate[2]		0.525	1.050	0.558	0.372	0.390	0.403	0.052
	% rec. catch[3]		26.2	52.5	27.9	18.6	19.5	20.2	2.6
	Rec. lbs.[4]		824	4,646	2,491	1,467	2,280	272	4
Clubfoot Creek	Total male catch			357					
	Daily rec. rate[1]			0.035[8]					
	Mon. rec. rate[2]			0.525					
	% rec. catch[3]			26.2					
	Rec. lbs.[4]			94					
	Total male catch	929	61,253	139,939	226,430	142,128	98,506	13,913	157
	Rec. lbs.[4]	99	19,548	102,387	66,589	26,613	18,029	2,159	4
	Mon. prop. rec.[2]	0.106	0.319	0.732	0.294	0.187	0.183	0.155	0.025

[1] Estimated daily recruitment rate.
[2] Estimated monthly recruitment rate (based on number of days from the start of fishing in the month to the end of the month, or to the end of fishing in the month).
[3] Estimated per cent of recruits in catch.
[4] Estimated pounds of males in the catch that were recruited during the month.
[5] Estimated proportion of male crabs in the catch that were recruited during the month.
[6] Average of 2 samples taken in month of April.
[7] Average of 5 samples taken in month of May.
[8] Average of 6 samples taken in month of June.
[9] Average of 8 samples taken in month of July.
[10] Average of 5 samples taken in month of August.
[11] Average of 4 samples taken in month of September.

the estimated decreasing catch of crabs (residuals) from the population present each week prior to any given week (column 7). Although Table 10 shows the partitioning of catches from weeks 6 to 13, the same procedure was followed for the catches to and including week 25, 22–28 September.

Estimates of male abundance at the beginning of each week, 12–18 May (week 6) to 28 July–3 August (week 17), were calculated by applying the Leslie method to the catches in the following weeks from the male population at a given time. Using the following notation:

t is the variable associated with week,
N_0 is the population of commercial-size crabs at the beginning of week $t = 1$,
C_t is the catch of crabs from population N_0, during week t,
K_t is the cumulative catch from population N_0 to the beginning of week t,
f_t is the number of standard units of effort during week t,
C_t/f_t is the catch per standard unit of effort during week t from population N_0, and

TABLE 9.—*Recruits in the weekly catches of male crabs from the Neuse River, beginning 7 April 1958 and ending 9 November 1958*

Trotline			Crab trawl			Shrimp trawl			Total		
Catch of males (pounds)	Ratio of recruits	Recruits (pounds)	Catch of males (pounds)	Ratio of recruits	Recruits (pounds)	Catch of males (pounds)	Ratio of recruits	Recruits (pounds)	Catch of males (pounds)	Recruits	Ratio of recruits
			211	0.055	12				211	12	0.057
123	0.025	3	5,365	0.055	295				5,488	298	0.054
217	0.057	12	21,625	0.055	1,189				21,842	1,201	0.055
590	0.066	39	13,097	0.069	904				13,687	943	0.069
1,021	0.072	74	8,803	0.080	704				9,824	778	0.079
7,402	0.072	533	28,976	0.080	2,318				36,378	2,851	0.078
26,762	0.072	1,927	33,923	0.080	2,714				60,685	4,641	0.076
26,113	0.086	2,246	29,319	0.076	2,228				55,432	4,474	0.081
29,359	0.171	5,020	32,549	0.056	1,823	208	0.098	20	62,116	6,863	0.110
38,476	0.171	6,579	30,404	0.056	1,703	2,065	0.115	237	70,945	8,519	0.120
44,011	0.171	7,526	54,798	0.056	3,069	5,638	0.115	648	104,447	11,243	0.108
22,776	0.171	3,895	25,815	0.056	1,446	8,676	0.115	998	57,267	6,339	0.111
31,160	0.081	2,524	9,406	0.060	564	6,756	0.065	439	47,322	3,527	0.074
50,402	0.066	3,326	11,676	0.061	712	13,751	0.057	784	75,829	4,822	0.064
51,183	0.066	3,378	17,791	0.061	1,085	21,527	0.057	1,227	90,501	5,690	0.063
48,139	0.066	3,177	14,421	0.061	880	19,783	0.057	1,128	82,343	5,185	0.063
49,170	0.056	2,754	12,396	0.053	657	23,355	0.049	1,144	84,921	4,555	0.054
39,098	0.042	1,642	4,870	0.042	204	19,658	0.038	747	63,626	2,593	0.041
43,530	0.042	1,828	5,678	0.042	238	27,239	0.038	1,035	76,447	3,101	0.040
41,637	0.042	1,749	2,588	0.042	109	24,830	0.038	944	69,055	2,802	0.040
17,533	0.042	736	1,844	0.042	77	24,999	0.038	950	44,376	1,763	0.040
28,821	0.043	1,239	1,348	0.046	62	17,072	0.043	734	47,241	2,035	0.043
27,866	0.043	1,198	2,307	0.046	106	21,647	0.043	931	51,820	2,235	0.043
22,494	0.043	967	1,275	0.046	59	11,756	0.043	506	35,525	1,532	0.043
16,126	0.043	693	642	0.046	30	11,855	0.043	510	28,623	1,233	0.043
5,391	0.037	199				333	0.045	15	5,724	214	0.037
4,012	0.035	140	9	0.046	—	1,220	0.046	56	5,241	196	0.037
6,005	0.035	210				1,445	0.046	66	7,450	276	0.037
			166	0.046	8	382	0.046	18	548	26	0.047
1,467	0.037	54	467	0.046	21	1,450	0.045	65	3,384	140	0.041
157	0.012	2	604	0.026	16	518	0.025	13	1,279	31	0.024

c is the fraction taken by one unit of effort from the population during any week t.

The method of arranging the data to estimate the population at the beginning of week 6 (12–18 May) is shown in Table 11. In column 2 are the estimated catches each week (C_t) from the male population present 12 May (from Table 10). In column 3 are the estimated standard units of effort each week (f_t) on the population of males. These were obtained by multiplying total standard units of effort each week by the proportion of males estimated to be in the weekly catches. Catches per standard unit effort each week (C_t/f_t) of males belonging to the population present 12 May are in column 4. In column 5 are the cumulative catches (K_t) up to a given week. The catch per standard fishing unit (C_t/f_t) versus cumulative catch (K_t) is plotted in Figure 2. Assuming a linear relationship between catch per standard unit of effort (C_t/f_t) and cumulative catch (K_t), then the equation $C_t/f_t = cN_0 - cK_t$, can be derived (Ricker, 1958). Estimates of the slope and the C_t/f_t-axis intercept give estimates of c and cN_0, respectively. Estimates of c and cN_0 for the data in Table 11 were calculated by the least squares method (Snedecor, 1956), and are 0.000561 and 185.379, respectively, from which an estimate of N_0 equal to 330,000 (pounds) is obtained. Therefore, the line that best describes the relationship between C_t/f_t and K_t is $C_t/f_t = 185.379 - 0.000561\ K_t$. The estimate of N_0 can also be obtained from Figure 2 by extrapolating the regression line to the K_t axis. This is the same as putting C_t/f_t equal to 0 in the above equation since, theoretically, the intercept on the K_t axis is the point where the catch per unit effort (C_t/f_t) is zero and therefore the cumulative catch at this point represents the population, N_0.

Population estimates for male crabs (Table 12) at the beginning of each week up to the week beginning 4 August were calculated by treating the catch–effort data after any given time in the same way as the data were handled for deriving the 12 May abundance estimate. The number of weeks of data used to calculate the estimate is in parentheses alongside each population estimate. These numbers decline

TABLE 10.—*Estimates of the pounds of male crabs caught each week that were recruits during the week and during previous weeks, 12 May–6 July 1958*

Week No.	Date	Estimated catch of males	Week recruited	Proportion of recruits	Catch of recruits	Residuals
6	12–18 May	36,378	6	0.078	2,837	33,541
7	19–25 May	60,685	7	0.076	4,612	56,073
			6	0.156	8,747	47,326
8	26 May–1 June	55,432	8	0.081	4,490	50,942
			7	0.152	7,743	43,199
			6	0.156	6,739	36,460
9	2–8 June	62,116	9	0.110	6,833	55,283
			8	0.162	8,956	46,327
			7	0.152	7,042	39,285
			6	0.156	6,128	33,157
10	9–15 June	70,945	10	0.120	8,513	62,432
			9	0.220	13,735	48,697
			8	0.162	7,889	40,808
			7	0.152	6,203	34,605
			6	0.156	5,398	29,207
11	16–22 June	104,447	11	0.108	11,280	93,167
			10	0.240	22,360	70,807
			9	0.220	15,578	55,229
			8	0.162	8,947	46,282
			7	0.152	7,035	39,247
			6	0.156	6,122	33,125
12	23–29 June	57,267	12	0.111	6,357	50,910
			11	0.216	10,996	39,914
			10	0.240	9,579	30,335
			9	0.220	6,674	23,661
			8	0.162	3,833	19,828
			7	0.152	3,014	16,814
			6	0.156	2,623	14,191
13	30 June–6 July	47,322	13	0.074	3,502	43,820
			12	0.222	9,728	34,092
			11	0.216	7,364	26,728
			10	0.240	6,415	20,313
			9	0.220	4,469	15,844
			8	0.162	2,567	13,277
			7	0.152	2,018	11,259
			6	0.156	1,756	9,503

as the fishing season continues because the catch–effort data for the weeks at the end of the season reflected changes in catchability due to weather rather than changes in abundance with constant catchability. Also in Table 12 are total population estimates obtained by dividing the estimates of male abundance by the ratio of commercial-size males to the total catch during the following week.

Confidence limits for the population of male crabs 7 July (week 14, $\hat{N}_0 = 561{,}000$ pounds) were obtained by finding the roots of the quadratic equation, $N^2(\hat{k}^2 - t_\alpha^2 s^2 c_{22}) - 2N[\hat{k}(\widehat{kN}) - t_\alpha^2 s^2 c_{12}] + [(\widehat{kN})^2 - t_\alpha^2 s^2 c_{11}] = 0$ (DeLury, 1951). In terms of the notation presented earlier, and letting m equal the number of observations, then:

$$\hat{k} = \hat{c}, \qquad \widehat{kN} = \widehat{cN_0},$$
$$c_{11} = \Sigma K_t^2/m[\Sigma K_t^2 - (\Sigma K_t)^2/m],$$
$$c_{12} = \Sigma K_t/m[\Sigma K_t^2 - (\Sigma K_t)^2/m], \quad \text{and}$$
$$c_{22} = 1/[\Sigma K_t^2 - (\Sigma K_t)^2/m].$$

The variance about the regression line is set equal to s^2, and ". . . t_α is the tabulated t-value at the 1-α confidence level with m-2 degrees of freeedom. . ." (DeLury, 1951).

The 95% confidence limits for the population estimate of 561,000 pounds of male crabs on 7 July were 514,000 and 624,000 pounds. Dividing these limits by 0.779, the ratio of males estimated to have been caught during the week 7–13 July (75,829 pounds, Table 7) to the total catch during the week (97,375 pounds, week 14, Table 1), estimates of the confidence limits (660,000 and 801,000 pounds) for the total population (716,000 pounds) on 7 July were obtained.

The confidence limits derived for the total population 7 July are minimal limits mainly because three factors have not been taken into account. These factors are as follows:

TABLE 11.—*Data used in the Leslie method for obtaining an estimate of the population of commercial-size male crabs on 12 May 1958*

Week	Catch of male crabs (C_t) (pounds)	Standard fishing units (f_t)	Catch per standard fishing unit (C_t/f_t) (pounds)	Cumulative catch (K_t) (thousands of pounds)
12 May–18 May	33,541	194	172.9	0.0
19 May–25 May	47,326	248	190.8	33.5
26 May–1 June	36,460	243	150.0	80.9
2 June–8 June	33,157	301	110.2	117.3
9 June–15 June	29,207	357	81.8	150.5
16 June–22 June	33,125	352	94.1	179.7
23 June–29 June	14,191	269	52.8	212.8
30 June–6 July	9,503	244	38.9	227.0
7 July–13 July	13,115	256	51.2	236.5
14 July–20 July	13,663	248	55.1	249.6
21 July–27 July	10,865	234	46.4	263.3
28 July–3 August	9,887	227	43.6	274.2

1) the variance of the ratio (0.779) used to convert male population limits to total population limits.

2) the variance of the male recruitment rates for the weeks after 7 July. These rates were used to eliminate recruits from the catches after this date. This was necessary so that the portions of the remaining weekly catches would be from the "closed" (DeLury, 1951) population on 7 July.

3) the distribution of the C_t/f_t values possibly departing somewhat from normality.

Confidence limits were determined for the population on 7 July rather than another date because, in later sections of this paper, estimates are obtained for this same date by other methods.

Alternate method using catch, effort, and recruitment data

Another method of estimating population size employing catch and effort data, and estimates of recruitment, was suggested by Dr. D. G. Chapman of the Department of Mathematics at the University of Washington. The derivation of the method and its application to the crab data are presented.

Let C_t/f_t be the catch per standard unit effort in week t. Under the assumption that the units of effort do not compete with each other (DeLury, 1947),

$$C_t/f_t = c\bar{N}_t\,, \qquad (1)$$

TABLE 12.—*Weekly Neuse River crab catch and estimates of population in thousands of pounds, 12 May–4 August 1958*

[estimates of population are for the beginning of the week]

Week	Catch		Population estimates	
	Males	Total	Males	Total
6	36	43	330 (12)[1]	394
7	61	73	346 (12)	414
8	55	68	361 (12)	446
9	62	79	396 (12)	504
10	71	91	446 (12)	572
11	104	132	477 (12)	605
12	57	73	554 (12)	710
13	47	60	596 (12)	761
14	76	97	561 (12)	716
15	90	118	530 (11)	695
16	82	108	509 (10)	670
17	85	112	492 (9)	648

[1] See text for explanation.

where c is the proportion of the population captured during week t by one unit of effort, and $\bar{N}_t$ is the average population size during the week. If N_t equals the population size at the end of week t and N_{t-1} the population size just previous to week t, then the approximate average population size ($\bar{N}_t$) during week t can be described as $(N_{t-1} + N_t)/2$ and equation (1) can be written

$$C_t/f_t = c(N_{t-1} + N_t)/2\,. \qquad (2)$$

Let the recruits (R_t) to the population during week t be expressed as

$$R_t = r_t(N_{t-1} + N_t)/2\,, \qquad (3)$$

where r_t is a certain fraction of the average population in week t. However, no functional relationship of recruitment rate (r_t) with population size is implied. Now considering the population at the end of week t,

$$N_t = N_{t-1} - C_t + R_t\,, \qquad (4)$$

where C_t is the catch during week t, and substituting equation (3) for R_t,

$$N_t = N_{t-1}[(2+r_t)/(2-r_t)] - C_t/(2-r_t). \qquad (5)$$

Substituting equation (5) for N_t in equation (2)

$$C_t/f_t = (c/2)\{N_{t-1}[(2+r_t)/(2-r_t)] - 2[C_t/(2-r_t)] + N_{t-1}\} \qquad (6)$$

or

$$C_t/f_t = c\{N_{t-1}[2/(2-r_t)] - C_t/(2-r_t)\}. \qquad (7)$$

Choosing some starting point, say $t = 0$, then the catch per standard unit of effort during the first week equals

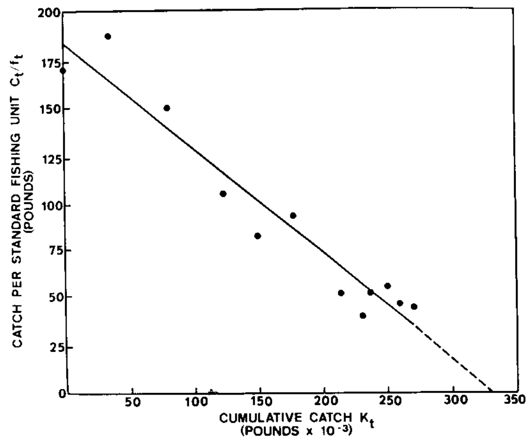

FIGURE 2.—The estimated catch per unit of effort of male crabs versus the cumulative catch from the male population on 12 May 1958.

$$C_1/f_1 = c\{N_0[2/(2-r_1)] - C_1/(2-r_1)\} \quad (8)$$

or

$$[(2-r_1)/2]C_1/f_1 = cN_0 - cC_1/2. \quad (9)$$

During the second week,

$$C_2/f_2 = c\{N_1[2/(2-r_2)] - C_2/(2-r_2)\}, \quad (10)$$

and from equation (5), letting $N_1 = N_t$,

$$C_2/f_2 = c[\![[2/(2-r_2)] \times \{[N_0(2+r_1)/(2-r_1)] - 2C_1/(2-r_1)\} - C_2/(2-r_2)]\!] \quad (11)$$

or

$$[(2-r_1)(2-r_2)/2(2+r_1)]C_2/f_2 = cN_0 - c\{2[C_1/(2+r_1)] + (2-r_1)C_2/2(2+r_1)\}. \quad (12)$$

For any week, t, after the second week

$$[(2-r_t)\ldots(2-r_1)/2(2+r_t)\ldots(2+r_1)] \times C_t/f_t = cN_0 - c\{2[C_1/(2+r_1)] + 2[C_2(2-r_1)/(2+r_1)(2+r_2)] + \ldots + 2[C_{t-1}(2-r_{t-2})\ldots(2-r_1)]/[(2+r_{t-1})\ldots(2+r_1)] + C_t(2-r_{t-1})\ldots(2-r_1)/[2(2+r_{t-1})\ldots(2+r_1)]\}. \quad (13)$$

If the recruitment rate, catch, and standard units of effort for each week are known, a set of equations similar to (9) and (12) can be calculated from the general equation (13). Letting Y_t equal the left-hand sides of these equations and X_t equal the coefficients of the minus c terms, the unknown parameters cN_0 and c can be estimated by the usual regression methods.

Starting at 12 May, weekly catch and effort data and the estimates of the weekly recruitment rates were substituted in equation (13) to obtain the Y_t and X_t values shown in Table 13 and Figure 3. Considering $Y_t = cN_0 - c\,X_t$, and treating Y_t as a dependent normally distributed variable with equal variances for each value of X the independent variable, "least squares" estimates were calculated for the parameters cN_0 and c. The estimate of c, the catchability, was 0.000442 and of N_0, the population on 12 May, was 448,549 pounds. The regression of Y_t on X_t was highly significant.

The weekly recruitment rates presented in Table 13 were calculated from the daily rates in Table 4. During the week of 12–18 May, for example, the recruitment rate shown in Table 13 (0.147) was obtained by summing the daily rate of 2.1% (1–15 May, Table 4) for 12, 13, 14, and 15 May; and the daily rate, also 2.1% (16–31 May, Table 4), for the remainder of the week, 16, 17, and 18 May.

These recruitment rates (Table 13) are estimates of the total pounds of crabs recruited during the week to the commercial-size population at the beginning of the week. In the derivation of the above method of estimating population size, especially in equation (3), it would have been more correct to use instantaneous weekly recruitment rates. However, the weekly total recruitment rates were not converted to the slightly lower instantaneous weekly rates because the use of the higher total recruitment rates compensates in a rough manner for the unmeasured small amount of growth in weight (as contrasted to the increase in weight due to recruitment) of the commercial-size crab population.

Estimates of the population at the end of the week (Table 14) were obtained by successive substitution into equation (5) of the catch and recruitment rate estimates for the week (Table 13), as well as the population estimate at the beginning of the week. As an example, the population estimate at the

TABLE 13.—*Weekly crab catch per standard unit of effort, and recruitment rate estimates for Neuse River, 12 May to 28 September 1958. Cumulative products of $(2 - r_t)$ and $(2 + r_t)$ used in equation (13) to determine Y_t and X_t values, are also shown*

Week	Catch per standard unit effort (C_t/f_t) (pounds)	Recruitment rate (r_t)	Cumulative product of $(2 - r_t)$	Cumulative product of $(2 + r_t)$	Y_t	X_t
12–18 May	186.0	0.147	1.8530	2.1470	172.33	2,167.00
19–25 May	244.5	0.147	3.4336	4.6096	195.51	72,032.12
26 May–1 June	226.7	0.161	6.3144	9.9613	155.27	124,512.05
2–8 June	203.9	0.245	11.0818	22.3631	113.42	170,864.93
9–15 June	196.4	0.245	19.4486	50.2052	85.40	212,897.56
16–22 June	292.5	0.245	34.1323	112.7107	99.43	256,123.54
23–29 June	210.0	0.245	59.9022	253.0355	55.80	287,210.05
30 June–6 July	194.5	0.175	109.3215	550.3522	42.02	302,997.27
7–13 July	293.3	0.161	201.0422	1,189.3111	53.57	318,657.09
14–20 July	370.0	0.126	376.7531	2,528.4754	58.60	336,895.08
21–27 July	350.6	0.112	711.3098	5,340.1400	49.32	353,735.97
28 July–3 Aug.	373.7	0.112	1,342.9529	11,278.3757	46.99	368,371.92
4–10 Aug.	266.1	0.112	2,535.4951	23,819.9295	29.91	380,038.30
11–17 Aug.	274.2	0.105	4,804.7632	50,140.9516	27.66	389,870.93
18–24 Aug.	283.7	0.084	9,205.9263	104,493.7431	26.04	399,069.71
25–31 Aug.	258.8	0.084	17,638.5548	217,764.9606	21.84	405,681.19
1–7 Sept.	238.4	0.175	32,190.3625	473,638.7893	17.62	410,620.66
8–14 Sept.	246.6	0.175	58,747.4116	1,030,164.3667	15.29	415,131,36
15–21 Sept.	202.3	0.091	112,148.8087	2,154,073.6908	11.01	448,464.97
22–28 Sept.	170.2	0.077	215,662.1591	4,474,011.0558	8.52	420,692.93

end of week 12–18 May was $(2 + 0.147)(448{,}549) / (2 - 0.147) - 2(43{,}342) / (2 - 0.147)$, or 472,936 pounds. This figure was then used as the value of N_{t-1} in equation (5) to calculate the population estimate at the end of week 19–25 May.

Parker method

This method involves the plot of the transformed daily ratios of the catch of marked fish to the total daily catch of fish (from a population in which recruitment is occurring) against the number of days after marking. If the transformed ratios are plotted on the Y-axis, and the number of days after marking on the X-axis, then an estimate of the initial population can be derived from the intercept on the Y-axis (Parker, 1955).

In using this method to estimate the population of fish of the genus *Lepomis* in a Wisconsin lake, Parker worked with fixed fishing gear and assumed that (1) the catchability of tagged and untagged fish was the same during each day, (2) the tagged fish were randomly dispersed, and (3) the absolute rate of recruitment was constant during the fishing period after tagging. It is not clear whether Parker assumed that the number of recruits or the rate of recruitment to the catchable population was constant. For the present assumptions 1 and 2 will be considered fulfilled. Discussion of all the assumptions and departures from them will be made in the following paragraphs and in a later section of the paper.

Parker (1955) did not give a detailed account of the method he used, and below is presented a possible theoretical basis for the method. This was developed from discussions with Dr. Gerald Paulik of the College of Fisheries, University of Washington, and from reference to an article on the subject of population estimates by Nose (1961). Assuming:

- N_0 equals the initial population at time, $t = 0$,
- T_0 is the number of marked individuals available at $t = 0$,
- Z equals the constant instantaneous daily recruitment rate to the catchable population,
- r equals the constant daily recruitment rate and $r = e^Z$,
- F_t equals the instantaneous rate of fishing during day t,
- M_t equals the daily instantaneous rate of natural mortality,
- s_t equals the fraction surviving at the end of day t,
- u_t equals the fraction (exploitation rate) of the marked members in the population present at the beginning of day t that are caught during day t,
- u_t' equals the exploitation rate on the

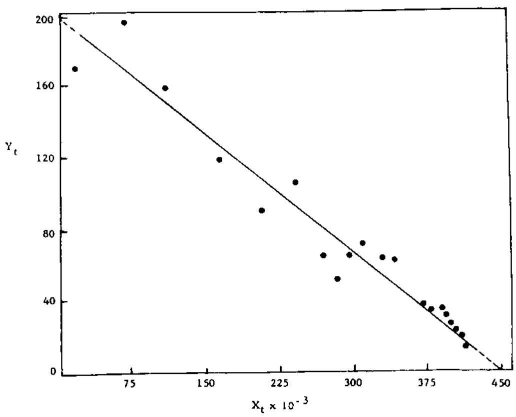

FIGURE 3.—X_t and Y_t values for 20 weeks beginning 12 May 1958. The X_t and Y_t values were obtained from equation (13).

unmarked members in the population during day t when recruitment is occurring, and

P_t equals the ratio of the catch of marked (R_t) to unmarked (C_t) members of the population in day t.

The number of marked fish recaptured during the first day after release equals u_1T_0 and the catch of unmarked fish equals $u_1'N_0$. During the second day, the marked and unmarked fish recaptured equal $u_2T_0s_1$ and $u_2'N_0s_1r$, respectively. The ratio of marked to unmarked fish caught during the second day (P_2) is $u_2T_0s_1 : u_2N_0s_1r$, and during any day t,

$$P_t = u_tT_0s_0s_1 \ldots s_{t-1}/u_t'N_0r^{t-1}s_0s_1 \ldots \ldots s_{t-1}, \tag{14}$$

where s_0 equals one. Assuming that the survival rate each day is the same for the marked and unmarked fish, then equation (14) reduces to

$$P_t = u_tT_0/u_t'N_0r^{t-1}. \tag{15}$$

The exploitation rate on the marked fish during any day t (u_t) can be expressed as $u_t = F_t[1-\exp-(F_t+m_t)](F_t+M_t)^{-1}$, the unmarked fish ($u_t'$) as $F_t[1-\exp-(F_t+M_t-Z)](F_t+M_t-Z)^{-1}$. Dividing u_t by u_t', then

$$\frac{[1-\exp-(F_t+M_t)](F_t+M_t)^{-1}}{[1-\exp-(F_t+M_t-Z)](F_t+M_t-Z)^{-1}}$$

can be approximated by

$$[1-\tfrac{1}{2}(F_t+M_t)][1-\tfrac{1}{2}(F_t+M_t-Z)]^{-1}. \tag{16}$$

This in turn can be approximated by

$$\frac{\exp-\tfrac{1}{2}(F_t+M_t)}{\exp-\tfrac{1}{2}(F_t+M_t-Z)}. \tag{17}$$

Simplifying this fraction (17), u_t/u_t' is shown to equal approximately $1/\exp \tfrac{1}{2}(Z)$ or, in terms of the daily recruitment rate, $1/r^{1/2}$.

Referring to equation (15), and letting $1/r^{1/2}$ replace u_t/u_t', then the estimate of the ratio of marked to unmarked fish on any day t, equals

$$E(p_t) = T_0/N_0r^{(2t-1)/2}. \tag{18}$$

Taking the natural logarithm of equation (18) and letting Y_t equal the natural logarithm of the ratio of the catch of marked to unmarked fish on day t, then

$$Y_t = [\ln(T_0/N_0) + \tfrac{1}{2}\ln r] + (-\ln r)t. \tag{19}$$

Equation (19) suggests a straight line relationship might exist between the logarithm of P_t and the days after release (t). Knowing T_0 and estimating r from the slope of the straight line, an estimate of the initial population N_0, can be obtained from the Y-axis intercept.

If one assumes, as Parker (1955) did, that the logarithm of the P_t values will give an approximate linear relationship with time, and that each of the values are from approximately normally distributed populations with

TABLE 14.—*Estimates of the population of commercial-size crabs obtained by successive substitution into equation,* $N_t = [(2+r_t)(N_{t-1})/(2-r_t)] - 2C_t/(2-r_t)$

[estimates of population are for the end of each week]

Week	Population estimate (pounds)
5–11 May	448,549
12–18 May	472,936
19–25 May	468,792
26 May–1 June	477,415
2–8 June	521,023
9–15 June	562,855
16–22 June	569,319
23–29 June	644,993
30 June–6 July	702,612
7–13 July	719,736
14–20 July	703,287
21–27 July	672,703
28 July–3 August	633,745
4–10 August	620,128
11–17 August	582,345
18–24 August	538,336
25–31 August	523,940
1–7 September	555,432
8–14 September	585,476
15–21 September	591,919
22–28 September	599,324

TABLE 15.—*Data used in Parker's method to estimate the crab population in the Neuse River on 4 July 1958*

Date	Recoveries (R_t) (number)	Catch (C_t) (thousands of pounds)	Logarithm of R_t/C_t (Y_t)	Days after end of marking (X_t)
7 July	13	21.8	−0.54696	4
8 July	10	16.5	−0.50077	5
9 July	7	16.0	−0.82668	6
10 July	7	27.5	−1.36828	7
11 July	6	15.0	−0.91629	8
14 July	3	32.0	−2.36713	11
15 July	1	22.0	−3.09104	12
16 July	6	22.3	−1.31283	13
17 July	2	23.4	−2.45959	14
18 July	3	18.0	−1.79176	15
21 July	3	31.4	−2.34820	18
22 July	1	16.6	−2.80940	19
23 July	3	18.6	−1.82455	20
24 July	1	22.7	−3.12236	21
25 July	2	17.8	−2.18605	22
28 July	3	34.6	−2.44524	25
29 July	3	31.7	−2.35771	26
30 July	1	18.4	−2.91235	27

equal variances, then least squares estimates of the slope and Y-axis intercept are the best estimates of these parameters (Snedecor, 1956).

The estimate of the crab population on 4 July 1958, was obtained using Parker's method. During the week preceding 4 July, 384 tagged crabs of both sexes were released, 227 near Goose Creek and 157 near Oriental. Sixteen of these crabs recovered during the week preceding 4 July and seven recovered after 4 July by noncommercial fishing gears were considered not available to the commercial fishery during the period from 7 July to 30 July. This left 361 tagged crabs available to the commercial fishery. Molting by tagged male crabs is discussed in a later section of this paper. However, if near the end of the recovery period tagged males molted, recruitment rate estimates would show greater increases than those for population size. The increase in the estimates would be due to change in weight of the population from growth of commercial-size male crabs. In Table 15 are the recoveries, R_t, made each fishing day beginning 7 July and ending 30 July. The catches each day, C_t, the natural logarithms of the P_t or R_t/C_t values, and the number of days after 3 July (the last day of tagging prior to 4 July) are also in Table 15. The equation of the best fitting linear regression line (Figure 4), considering the logarithms of R_t/C_t as Y_t values and days after 3 July as X_t values, is $\hat{Y}_t = -0.64996 - 0.086036 X_t$. The slope of this regression line was highly significant. From the value of the Y-axis intercept, −0.64996, one-half the slope (0.086036/2) was subtracted (see equation 19). Taking the antilogarithm of the remainder and multiplying by 10^3, an estimate was obtained of the initial ratio of tagged to untagged crabs (T_0/N_0) on 4 July. Dividing the number of marked crabs available 4 July (361) by this estimate of T_0/N_0, the population estimate of 722,000 pounds of crabs for 4 July was obtained.

An estimate of the error in the transformed R_t/C_t value when $t = 0$ was calculated (Ricker, 1958). Using the estimate of error, 95% confidence limits for the population on 4 July were 516,000 and 1,009,000 pounds.

The use of the ratios of the numbers of marked crabs to pounds of unmarked crabs caught each day, rather than pounds of marked to unmarked crabs, did not affect the estimate of population as the tagged crabs at the time of release were considered representative of the commercial crab population 5 inches or more in width. Also, the ratio of commercial-size crabs 4.5–5 inches wide to

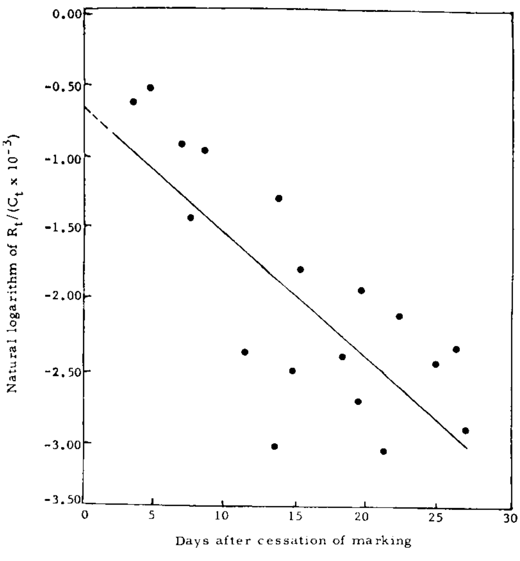

FIGURE 4.—The natural logarithm of the daily recoveries (R_t) divided by the daily catch ($C_t \times 10^{-3}$) for the tagged crabs released in the week prior to 4 July 1958.

crabs greater than 5 inches was assumed to be constant during the period from 4 July to 30 July.

Estimates of the population at the beginning of the weeks of 23 June and 21 July were calculated by the Parker method from recoveries of tagged crabs released in the weeks immediately prior to these dates. The estimates of the population were 657,000 and 789,000 pounds, respectively, for these dates.

In a later paper, Parker (1963) assumes when taking point samples that the expected numbers of marked individuals recaptured will follow a Poisson distribution. Parker then presented a method of estimating three population parameters, N_0, i $(= F + M)$, and r (in numbers), when minimizing the variance of differences between the expected and observed numbers of marked fish recaptured. Because some of the important assumptions necessary to the model outlined by Parker (1963) for estimating the population parameters were not satisfied by the Neuse River crab population, this method (Parker, 1963) was not used in this study.

CRABS AVAILABLE TO THE FISHERY

An estimate of the commercial-size crabs available to the fishery in 1958 was obtained by adding the total catch to the estimated population at the end of the fishing season. It was assumed that natural mortality and predation upon commercial-size crabs during the fishing season were negligible (see Discussion) and that 44% of the female recruits emigrated and escaped the fishery during the fishing season.

The latest date during the fishing season for which population estimates are available, calculated by all three methods, is 21 July. The Leslie method gave an estimate of 670,000 pounds (Table 12); the Alternate method, using catch, effort, and recruitment data, 703,000 pounds (Table 14); and the Parker method, 789,000 pounds. Because no evidence suggested that one particular method gave more accurate estimates, the average of these estimates, 721,000 was considered the best estimate of the population on 21 July.

In order to obtain an estimate of the population at the end of the fishing season, the following procedure was used:

The estimate of the population 21 July was split into estimates of the populations of male and female crabs on this date (552,000 and 169,000 pounds). This was accomplished by multiplying the total population by the ratio of males (0.765) estimated to be in the catch during the week of 21–27 July (see Tables 1 and 7). The male population estimate of 552,000 pounds was then multiplied by 2×0.063 (see Table 9, last column), the estimated male recruitment rate for the week, giving an estimated 70,000 pounds of male recruits during the week. The catch of male crabs during the week was estimated as 82,000 pounds (Table 9). Adding the recruits and subtracting the catch from 552,000 pounds, an estimate of 540,000 pounds was obtained for the population of male crabs at the beginning of the week of 28 July.

Estimates of the male crab population at the beginning of each week up to 22 September were obtained by continuing the above process. The estimate for 22 September was 378,000 pounds of male crabs. Estimates of the male crab population for later dates were not calculated because estimates of the recruitment rate and sex ratio, obtained from the catch samples were not available after the week of 22–28 September. Also, during October and November the number of recruits to the population was negligible, as suggested by the almost complete absence of soft or peeler crabs in the fishermen's catches. Using the male crab population estimate for 22 September, a total population estimate of 508,000 pounds was calculated for this date by dividing the male crab population by 0.744 (the estimated ratio of male crabs in the total catch during the week of 22–28 September).

In the Neuse River from 7 April to 10 November, 1958, 2.140 million pounds of crabs were estimated to have been available to the fishery. This figure is the estimated population on 22 September, 0.508 million pounds, and the total catch of the three major types of gear up to 22 September, 1.632 million pounds. It was assumed that recruitment from 22 September to 9 November was negligible and that for the entire season a constant percentage of the female crabs recruitable to the population emigrated to Pamlico Sound precluding availability to capture in the river.

DISCUSSION

Influence of weather and competition between units of gear on the catch per unit of effort

For almost 2 weeks in the middle of the fishing season (22 June to 3 July) northeast winds from 5 to 11 knots reduced the amount of successful fishing time each day and, as a result, the daily catch per unit of effort. Of the three major fishing gears, trotlines would be most affected by weather. However, the multiple regression of trotline catch per unit of effort in relation to average wind speed and average wind direction each day during the fishing season was not significant. Therefore, weather was considered not to have reduced the usefulness of catch per unit of effort as a measure of relative abundance, except at the very beginning and end of the fishing season and from 22 June to 3 July.

If an increase or decrease in the number of units of effort is followed by an immediate decrease or increase in catch per unit of effort, competition between fishing units may be indicated. These relationships were not found during the season (Table 1), however, and gear competition as it affected catchability was not considered present in the fishery.

Ratio of soft crabs to hard crabs

The numbers of soft crabs and the pounds of hard crabs caught by trawl fishermen in 1958 were obtained from the records of crab dealers. After converting the numbers of soft crabs to estimated weight of soft crabs,[2] ratios of soft to hard crabs each day were calculated. These ratios of soft to hard crabs were estimates of the daily recruitment rates. They agreed with the recruitment rates calculated from the catch samples (Table 4).

Natural mortality and predation

Continuous inspection of catches made by trawls during the fishing season revealed dead crabs only in the early spring. The state of deterioration of these dead crabs suggested they died during the winter. The natural mortality of commercial-size crabs available during the fishing season, therefore, was considered negligible. There was no reason to believe that natural mortality of tagged crabs differed from that of the untagged crabs. Of the releases in the Neuse River and Pamlico Sound, there were no tag returns by trawl fishermen or others in which tags were reported attached to dead crabs.

Fish predation upon precommercial- and commercial-size crabs in the Neuse River was not studied. Studies by Roelofs (1950, 1954) in Pamlico Sound and tributary waters suggested that fish predation, especially upon the larger size crabs in these waters, was negligible. Roelofs (1954) reported that the croaker, *Micropogon undulatus* (Linnaeus), and the spot, *Leiostomus xanthurus* Lacépède, "comprise about 90% of the benthonic fish population in Pamlico Sound and tributary waters." Of the more than 200 croaker and spot stomachs he examined, decapods were found in about 4%. Most of these decapods were not blue crabs but were commercially unimportant shrimps and prawns of the suborder Macrura.

Loss of tags

Mature females do not molt. There is the possibility, however, that some of the smaller tagged males (5 to 6 inches) molted and lost their tags in the 2-month periods after release, when most recoveries were made. For the tagged males released into the Neuse River, an analysis of variance test of the difference between the mean width of tagged male crabs recovered and the mean of those not recovered was not significant (5% level). It was concluded, therefore, that smaller tagged male crabs did not molt at a faster rate than the larger tagged male crabs. This conclusion does not eliminate the possibility of both size groups molting at the same rate. However, since almost all the shed carapaces caught by trawl fishermen were less than 5 inches in width, and since no recoveries of tags attached to shed carapaces were reported by these fishermen, it was concluded that tag loss due to molting was negligible.

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[2] A factor of 3.47 soft crabs per pound was used to convert numbers to pounds of soft crabs. Unpublished data, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Beaufort, N. C.

Since tag loss by molting and from natural mortality and predation are considered negligible or insignificant, the reasons for the low tag return percentages from the releases in Pamlico Sound and the Neuse River must be connected with the fishery in these areas. In Pamlico Sound the low return percentage (19%, Table 2) is attributed to the intermittent fishery. In the Neuse River, however, the fishery took 81% of the estimated 2.1 million pounds of available crabs, but only approximately 20% of the tagged females and 34% of the males (Table 2). The low percentage return from females is attributed mainly to their movement out of the river into Pamlico Sound. For the tagged males released in the river the percentage return from those released during the first half of the crabbing season (40%) to the returns from releases during the latter half, (28%) suggests that equal amounts of fishing effort on the early and late releases would have resulted in a total return of at least 40%. In the following section of this paper an explanation is given for this still low percentage of tag returns.

Selectivity and availability

If the three major types of fishing gear were selective for any particular size class of crabs, this selectivity could have caused erroneous estimates of recruitment rate calculated from catch samples. However, the frequency distribution of the crabs in the catch samples suggested nonselectivity for particular size groups of crabs.

The availability of the total crab population to fishing in the Neuse River was indicated by the relative number of daily returns from tagged crabs, and by the estimates of the average daily recruitment rates calculated in the Parker method. Returns, from the releases during the week previous to 7 July (Table 15), and the estimate of the average daily recruitment rate obtained from the relation of the tagged to untagged crabs in the daily catch after 4 July (Parker method) will be used to explain this statement.

It is assumed that the rate of natural mortality for the tagged crabs released in the few days prior to 4 July was not different from the rate for untagged crabs, that the tagged crabs were randomly distributed or that fishing effort was uniform on all stocks in the river population, and under these assumptions, and with approximately equal catches during each week after tagging, the proportionate weekly reduction in the number of tagged crabs recovered should reflect the approximate weekly recruitment rate. In other words, if the recruits during each of 2 weeks are approximately 25% of the population at the beginning of the week, and the catches during both weeks are equal, then the number of tags recovered the second week should be approximately 25% less.

During the 3 weeks after 4 July, the catch averaged 108,000 pounds per week (Table 1) and the catches per standard unit of effort were 293, 370, and 351 pounds (Table 1), suggesting an increase in population of at most 25%. However, the decreasing tag returns (43, 15, 10) suggested that the population increased about 55% each week. Only part of this decrease in the number of returns each week can be attributed to recruitment. Based on knowledge of the fishery and tag return locations, the major causes of this apparent decrease were the concentration of the fishery and the tagged crabs in the release areas during the first week, and the reduced availability of slower dispersing tagged crabs relative to the fishing effort in the second and third weeks.

The estimate (0.086) of the average instantaneous daily recruitment rate, Z (see Parker method, equation 19 where $Z = \ln r$), was the regression slope relating the logarithm of the catch of tagged and untagged crabs to the days after 4 July. On the basis of the recruitment rates estimated from the catch samples (Table 4) and the catch per standard unit of effort for the 3 weeks after 4 July, an actual Z value of 0.086 was extremely unlikely. Based on the estimated increase in population size and on catch per unit of effort, the actual average daily instantaneous recruitment rate was, at most, 0.05. The difference between 0.05 and the estimated 0.086 can be considered a measure of the increase in the availability of untagged crabs (movement of the fishing fleet from the release areas) relative to the decreased availability of tagged crabs.

SUMMARY AND CONCLUSIONS

1. During 1958 trotlines, crab trawls, and shrimp trawls caught 1.7 million pounds of blue crabs in the Neuse River, North Carolina. Estimates of the population of crabs in the river were calculated from the catch–effort, catch–sampling, and tag-recovery data.

2. A tagging study and observation of fishermen's catches indicated that commercial-size male crabs remained in the river until fall, whereas 44% of the females migrated to the more saline waters of Pamlico Sound precluding their capture in the river.

3. Estimates of daily recruitment rates were calculated from the ratios of precommercial (crabs 3.4 to 4.5 inches carapace width) to commercial-size crabs (>4.5 inches) in samples of unculled crabs obtained from commercial fishermen.

4. The first of three methods used to estimate population size was the Leslie method (Leslie and Davis, 1939). To satisfy the conditions for a closed population, only catch and effort data for male crabs, reduced by the estimated weight of male recruits, were used. From the estimates of the male crab population, estimates for the total population were obtained by using the ratios of male to female crabs in the catch. Minimal 95% confidence limits for the total population on 7 July, 716,000 pounds, were 660,000 and 801,000 pounds.

5. The second method of population estimation also employed catch, effort, and recruitment data. Using this method, an estimate of the population on 12 May was calculated. By successive substitution of the catch and estimated recruitment rates during the weeks following 12 May, an estimate of the population on 7 July, 703,000 pounds, was obtained.

6. The third method involved the plot of transformed ratios of tagged to untagged crabs, caught daily, against the number of days after cessation of tagging (Parker, 1955). The 95% confidence limits for the estimate on 4 July, 722,000 pounds, were 516,000 and 1,009,000 pounds.

7. During 1958, it is estimated that 2.14 million pounds of crabs were available to the fishery in the Neuse River. Of this population, 1.63 million pounds were caught by the three major types of gear prior to 22 September; the remainder, 0.51 million pounds, is the estimate of the population on 22 September. The amount of recruitment for the remainder of the crabbing season after 22 September was negligible.

8. The effects of wind speed and direction as well as competition between fishing vessels on catchability were considered negligible throughout most of the fishing season.

9. The possibilities of (1) natural mortality of tagged and untagged crabs, (2) fish predation upon crabs, and (3) loss of tags by molting crabs sizably affecting the crab population or the estimates, were considered remote.

10. The ratios by weight of the daily catch of soft to hard crabs agreed with the recruitment rates calculated from the ratios of precommercial- to commercial-size crabs in the catch samples.

11. Estimates of the average daily instantaneous recruitment rate were derived from the Parker (1955) method for estimating population size. The high rates obtained were due not only to recruitment, but to changing availability of tagged and untagged crabs.

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